Effect of waterlogging on morphological changes and growth of six forage grasses

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ABSTRACT: Waterlogging from successive rain depressions causes problems for forage grasses in the low lying areas of northeast Thailand. Six promising forage grass cultivars [Ubon paspalum (*Paspalum atratum* cv. Ubon), Mombasa guinea (*Panicum maximum* cv. Mombasa), Purple guinea (*P. maximum* cv. Purple), Mulato II (*Brachiaria ruziziensis* x *B. decumbens* x *B. brizantha* cv. Mulato II), Cayman (*B. ruziziensis* x *B. decumbens* x *B. brizantha* cv. Cayman), and humidicola (*B. humidicola*)] were studied for waterlogging tolerance. The objectives were to evaluate these forage grasses on 1) the effect of waterlogging at late vegetative phase on morphological changes and growth; and 2) the effect of repeated waterlogging (with 30 days recovery period) at the late vegetative phase on morphological changes and growth. The results showed that: 1) Waterlogged grasses had yellow and dried out leaves and more adventitious roots; plant height, number of tillers, and leaf area were lower ($P < 0.05$); and total dry weight started to lower at 40 days of waterlogging compared to those of control ($P < 0.05$). Ubon paspalum tolerated best to waterlogging followed by humidicola, Cayman, Purple guinea, Mombasa guinea; while Mulato II was the most susceptible. 2) Repeated waterlogging with recovery period caused yellowish and dried out leaves, stimulated the production of adventitious roots, new leaves, and new shoots. Plant height was higher, but the number of tillers and leaf area were lower compared to those of control ($P < 0.05$). Waterlogging once with recovery period seemed to do no harm on grasses; but repeated waterlogging with recovery period as well reduced total dry weight ($P < 0.05$). Humidicola tolerated best to repeated waterlogging followed by Ubon paspalum, Cayman, Purple guinea, Mombasa guinea; while Mulato II was most susceptible.
Keywords: waterlogging, morphological changes, growth, forage grass

Introduction

Dairy cattle production in Thailand, with support from the government, has steadily increased over the years. In 2012, Thais consumed 940,000 t of milk (OAE, 2012). Beef cattle are reared mainly for domestic consumption (180,000 t of meat/y.); only some are exported to neighboring countries [6,000 t of meat and related products/y.; (DLED, 2012)].

Production of these ruminants requires a constant supply of good quality forage grasses. The forage project at the Faculty of Agriculture, Ubon Ratchathani University has evaluated many grass species over the past twenty years including Ubon paspalum (*Paspalum atratum* cv. Ubon), Mombasa guinea (*Panicum maximum* cv. Mombasa), Purple guinea (*P. maximum* cv. Purple), Mulato II (*Brachiaria ruziziensis* x *B. decumbens* x *B. brizantha* cv. Mulato II), Cayman (*B. ruziziensis* x *B. decumbens* x *B. brizantha* cv. Cayman), and humidicola (*B. humidicola*).

In the undulating areas in northeast Thailand, a problem which frequently occurs in the wet season is waterlogging. One to three depressions during August-September can cause a period of waterlogging in low lying areas [30% in this region; (Saengkum, 2000)]. Many of the improved grasses do not tolerate or perform well under

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waterlogging conditions (Hare et al., 1999; 2003). Therefore the objectives of this experiment were to evaluate the above six forage grasses on 1) the effect of waterlogging at the late vegetative phase on morphological changes and growth; and 2) the effect of repeated waterlogging (with 30 days recovery period) at the late vegetative phase on morphological changes and growth.

Materials and Methods

This experiment was conducted at Ubon Ratchathani University from May 2012 to April 2013. It composed of two trials; both were prepared similarly for pot trials and were carried out in a plastic greenhouse.

Seedlings of Ubon paspalum, Mombasa guinea, Purple guinea, Mulato II, Cayman, and humidicola were prepared in plastic germination trays [soil (Roi-et series): burnt rice husk: manure = 1: 2: 1 medium]. At 30 days after sowing seedlings were transplanted to pails [two seedlings/hill; three hills/pail (equidistant in a no. 16 plastic pail with 8 kg of soil: burnt rice husk: manure: lime = 30: 1: 1: 1 planting medium)]. At 50 days after sowing grasses received a surface application of 15-15-15 fertilizer at the rate of 32 kg/rai (1,600 m^2). Waterlogging began at 60 days after sowing, with the water level maintained at 10 cm above soil surface.

Grass samples (one clump/pail of each grass) were collected randomly and periodically as planned. Data collected included morphological changes, plant height (cm; soil surface to graspable top or stem length for humidicola), number of tillers/hill (tiller with two fully expanded or collar visible leaves), leaf area [cm^2; (Yoshida, 1981)], dry weight (gm/clump for senesced leaves, green leaves, and stems), and waterlogging tolerance.

Data obtained were analyzed by analysis of variance using IRRISTAT program, and Least Significant Difference was used for mean comparisons (Gomez and Gomez, 1983).

Trial 1 Effect of waterlogging at the late vegetative phase on morphological changes and growth of six forage grasses

This trial was a completely randomized design in factorial arrangement with four replications. In each replication there were four pails of each grass cultivar. The two factors were:

Factor 1 Two conditions of waterlogging - control and waterlogging at late vegetative phase

Factor 2 Six cultivars of grasses - Ubon paspalum, Mombasa guinea, Purple guinea, Mulato II, Cayman, and humidicola

In the waterlogging treatment, the water level was maintained throughout the period of 40 days. Grass samples were collected at 0, 10, 20, 30, and 40 days of waterlogging; and data recorded.

Trial 2 Effect of repeated waterlogging at the late vegetative phase on morphological changes and growth of six forage grasses

Experimental design was the same as in trial 1. The two factors were:

Factor 1 Two conditions of waterlogging - control and repeated waterlogging with recovery period at the late vegetative phase

Factor 2 Six cultivars of grasses - Ubon paspalum, Mombasa guinea, Purple guinea, Mulato II, Cayman, and humidicola

In repeated waterlogging, the water level was maintained throughout for the periods of 10, 20, and 30 days. When time was due for each treatment, the water was drained off completely for 30 days grass recovery (watered when needed to maintain grass growth), then grass samples were taken and data recorded. After the first sampling, the remaining grasses were re-waterlogged for 10, 20, and 30 more days and grass samples were collected and data recorded.

Recovery of grasses were ranked from 1-6 according to changes (change percentage) by comparing to those in the control treatment [1 had the most changes (not tolerant) while 6 the least (tolerant)]. Scores from the first and second assessments then summed up to find mean for comparison (Tanchai, 2005).

Results and Discussion

1. Effect of waterlogging at late vegetative phase on morphological changes and growth of six forage grasses

1.1 Morphological change Waterlogging in forage grasses, in general, caused yellowish and dried-out margins in the upper leaves and death in the lower leaves (**Table 1**). These grasses adapted to waterlogging by forming adventitious roots on nodes above water for survival (Donald, 1984).

Table 1 Morphological changes of six forage grasses at different durations of waterlogging during late vegetative phase

Grass	Duration of waterlogging				
	0 day	10 days	20 days	30 days	40 days
Ubon paspalum	Stems and leaves green; and some leaf margins yellowish-red and leaf tips slightly dried out.	Leaf margins turned purple and tips dried out; leaves died; and two to three adventitious roots formed.	Bottom leaves died increasingly; and adventitious roots netting at water level.	Bottom leaves and plant died increasingly; and adventitious roots continued netting at water level.	More bottom leaves died; new shoots formed; and adventitious roots netting extensively.
Mombasa guinea	Stems and leaves green; some bottom leaves yellow; and a few leaves died.	Leaf margins turned yellow and rolled; leaf tips dried out; and bottom leaves died increasingly.	Leaf margins turned yellow and dried out; and one to two adventitious roots formed above water.	Bottom leaves turned yellow and died increasingly; and adventitious roots elongated and increased in number.	Bottom leaves died; some new leaves developed; and adventitious roots further elongated.
Purple guinea	Stems, leaf bases and margins purple while blades green; some bottom leaves died; and one to three new shoots formed.	Leaf bases purple; leaf margins and tips turned yellow and died increasingly; and adventitious roots formed above water.	Stems and leaf bases purple; bottom leaves turned yellow and died increasingly; and adventitious roots elongated.	Stems and leaf bases purple; bottom leaves died increasingly; and adventitious roots red and further elongated.	Top leaves greenish-yellow, more bottom leaves died; some leaf tips dried out; and adventitious roots elongated.
Mulato II	Stems and leaves dark green; some bottom leaves yellow and died; and two to five new shoots formed.	Many leaves turned yellow and bottom leaves died; and adventitious roots developed in some plants.	More leaves yellow and died; new shoots and adventitious roots formed; root tips forked out into rootlets.	More leaves and stems died; new shoots and adventitious roots formed on nodes above water.	Many leaves died; new shoots had yellowish leaves; and lots of adventitious roots formed.
Cayman	Stems and leaves green; bottom leaves turned yellow and died; and new shoots formed.	Bottom leaves died; bottom leaves turned yellow, tips rolled and dried out; and a few adventitious roots developed.	More leaves died; few plants died; adventitious roots elongated and succulent; and one new shoots formed.	Stems slender and purple; many leaves died; new shoots developed; and adventitious roots further elongated and developed more.	Stems stiff and purple; more leaves died; leaves on new shoots turned yellow and wilt; and adventitious roots elongated.
Humidicola	Leaf tips pointed and green; some bottom leaves died; and many new shoots developed.	Bottom leaves turned yellow, rolled margins, and dried out tips; and new shoots formed.	Leaves turned yellow and died increasingly; new shoots grew up with one to two adventitious roots on each node.	More leaves died; and more new shoots formed.	More leaves died; stems stiff and bases turned purple; one to two new shoots formed; and more adventitious roots developed.

It was noted that as the period of waterlogging increased, leaves of Mombasa guinea, Mulato II, and Cayman became more yellowish and senescent, compared to Ubon paspalum and Purple guinea. Morphological changes of the grasses were the same as those reported by Hare et al. (2004) who found that a long period of waterlogging did not affect Ubon paspalum. Ten and 20 days of waterlogging caused yellowish and dryness in bottom leaves and up to 50% death of grasses respectively in Ruzi (*Brachiaria ruziziensis*) and Signal (*B*. *decumbens*) grasses (Hare et al., 2004).

1.2 Growth Growth of waterlogged grasses in terms of plant height, number of tillers, and leaf area were affected and started to lag behind control grasses after 10 and 20 days of waterlogging (data not shown). After 40 days waterlogging, plant height, number of tillers, and leaf area of waterlogged grasses were lower than those of control ($P < 0.05$; 140.5 ± 4.9 vs. 156.4 ± 4.9 cm, 13.2 ± 1.0 vs. 20.0 ± 1.0 tillers/hill, and 1,685 ± 189 vs. 4,064 ± 189 cm^2/hill respectively).

Waterlogging impedes root growth and affects nitrogen and phosphorus absorption (Dobermann and Fairhurst, 2000), consequently plant height was affected. Mulato II, Cayman, and humidicola produced approximately three times more tillers/hill than Ubon paspalum, Mombasa Guinea, and Purple Guinea (≈7.8 vs. 25.4). Tillering is an important grass characteristics, grasses with small stems and small leaves often produce more tillers compared to those with big stems and big leaves. Waterlogging also affects leaf growth and internode elongation due to lower gibberellin and cytokinin syntheses (Kozlowski and Pallardy, 1984) and higher ethylene synthesis (Taiz and Zeiger, 1991). This, then, affects leaf photosynthesis, and consequently the growth of grasses as a whole. This was similar to those reported by Luana and Dias-Filho (2008) - flooding caused a reduction in leaf growth resulting in a reduction in net photosynthesis and consequently a reduction of growth in brachiaria grasses.

After 40 days of waterlogging, Ubon paspalum produced the highest leaf area (4,677 ± 327 cm^2/hill) even though it had next to lowest plant height (123.3 ± 8.5 cm) and the lowest number of tillers/hill (6.0 ± 1.8).

1.3 Dry weight Prolonged excessive water did not reduce total dry weight of forage grasses up until 40 days of waterlogging (**Table 2**). This showed that grasses could tolerate quite well at the beginning of waterlogging. For control and waterlogged grasses, dry weight of senesced leaves, green leaves, and stems did not differ until 10, 20, and 30 days of waterlogging respectively (data not shown). Under unfavorable conditions, bottom leaves suffered first by relocating their reserves to the upper leaves, thereby difference in green leaf dry weight came after. Whereas the hardier plant part like stems were affected later. The cumulative effects of waterlogging then showed up in terms of total dry weight after 40 days period (68.0 ± 3.4 vs. 47.6 ± 3.4 g/hill).

Table 2 Effect of waterlogging at the late vegetative phase on total dry weight of six forage grasses

Factor	Treatment	Total dry weight (g/hill)				
		0 DOW[1/]	10 DOW	20 DOW	30 DOW	40 DOW
Waterlogging	Control	25.5 ± 1.8	33.2 ± 2.3	45.9 ± 3.1	49.8 ± 3.0	68.0 ± 3.4[a2/]
(A)	Waterlogged	23.0 ± 1.8	34.1 ± 2.3	41.2 ± 3.1	41.4 ± 3.0	47.6 ± 3.4[b]
	Average	**24.2**	**33.6**	**43.5**	**45.6**	**57.8**
Grass	UP[3/]	25.7 ± 3.1[b]	34.7 ± 4.0[b]	34.0 ± 5.3[b]	53.2 ± 5.2[a]	57.1 ± 5.9[b]
(B)	MG	35.7 ± 3.1[a]	48.4 ± 4.0[a]	56.6 ± 5.3[a]	56.5 ± 5.2[a]	69.5 ± 5.9[a]
	PG	34.4 ± 3.1[ab]	42.8 ± 4.0[ab]	59.3 ± 5.3[a]	44.3 ± 5.2[a]	57.1 ± 5.9[b]
	MII	21.0 ± 3.1[b]	29.0 ± 4.0[b]	37.8 ± 5.3[b]	50.4 ± 5.2[a]	56.7 ± 5.9[b]
	Cm	19.0 ± 3.1[b]	31.6 ± 4.0[b]	45.3 ± 5.3[ab]	48.4 ± 5.2[a]	74.3 ± 5.9[a]
	BH	9.5 ± 3.1[c]	15.3 ± 4.0[c]	28.0 ± 5.3[c]	20.7 ± 5.2[b]	32.2 ± 5.9[c]
	Average	**24.2**	**33.6**	**43.5**	**45.6**	**57.8**
CV (%)		39.7	33.6	34.6	32.2	28.8
LSD	A	ns[4/]	ns	ns	ns	9.7
($P < 0.05$)	B	8.9	11.5	15.3	14.9	16.9
	A x B	ns	ns	21.6	ns	ns

[1/] Days of waterlogging

[2/] Within a column for each effect, values followed by different letters are significantly different ($P < 0.05$)

[3/] UP = Ubon paspalum, MG = Mombasa guinea, PG = Purple guinea, MII = Mulato II, Cm = Cayman, and BH = *Brachiaria humidicola*

[4/] ns = non significant

The total dry weight of grasses was different from the beginning ($P < 0.05$; **Table 2**). Mombasa guinea - an erect and tufted grass with big stems and leaves - had a good start and maintained its growth throughout the waterlogging period. Cayman initially grew slowly in the first 10 days, but then growth accelerated. Both cultivars gave the highest total dry weight. Humidicola - a procumbent stoloniferous grass with small stems and leaves - produced very low total dry weight throughout.

1.4 Waterlogging tolerance After 40 days of waterlogging, Ubon paspalum tolerated best to waterlogging (top score of 36) followed by a group with similar scores: Humidicola (27), Cayman (26), and Purple guinea (25); whereas Mombasa guinea (19) and Mulato II (14) tolerated least to waterlogging (**Table 3**).

Table 3 Scores and ranks for 40 days waterlogging tolerance of six forage grasses

Parameter	Grass					
	UP[1/]	MG	PG	MII	Cm	BH
Plant height	6	1	3	4	5	2
Number of tillers	5	6	1	3	4	2
Leaf area	6	2	4	1	3	5
Senesced leaf dry weight	5	1	2	3	4	6
Green leaf dry weight	6	2	3	1	4	5
Stem dry weight	4	2	6	1	3	5
Total dry weight	4	5	6	1	3	2
Total score	36	19	25	14	26	27
Rank	1	5	4	6	3	2

[1/] UP = Ubon paspalum, MG = Mombasa guinea, PG = Purple guinea, MII = Mulato II, Cm = Cayman, and BH = *Brachiaria humidicola*

Ubon paspalum had the highest scores in height, leaf area, and green leaf dry weight. It should also be noted that this grass developed extensive adventitious roots (**Table 1**). Weier (1980) reported that there are free living nitrogen fixing microorganisms in the rhizosphere of some forage grasses especially paspalum. This, of course, was a benefit to Ubon paspalum for extra nitrogen supply. In addition this grass might be able to develop aerenchyma in its roots during waterlogging (Suwannasophon and Jampeetong, 2012), thus helping in air conducting for cell respiration.

Humidicola had the highest score (least change) in senesced leaf dry weight and relatively high scores in leaf area, green leaf dry weight, and stem dry weight. This grass tolerates strongly to waterlogging (Cardoso et al., 2013).

2. Effect of repeated waterlogging at the late vegetative phase on morphological changes and growth of six forage grasses

2.1 Morphological change Repeated waterlogging, in general, caused yellowish and dried out tips in the upper leaves of grasses and death in the lower leaves (**Table 4**). These grasses adapted to repeated waterlogging by forming adventitious roots above water for survival (Donald, 1984). It was noted that adventitious roots of Ubon paspalum were white rootlets netting all over the water surface, while those of other grasses were thicker and longer. The overall results were similar to those in 1.1 (**Table 1**).

Table 4 Morphological changes of six forage grasses at different durations of repeated waterlogging during late vegetative phase

Grass	Duration of waterlogging			
	0 day	10 days	20 days	30 days
Ubon paspalum	Leaves green with purple bases, yellowish-red rims, and dried out tips; and new leaves and shoots developed.	Leaf bases turned purple; bottom leaves turned yellow and died; adventitious roots shrank and died; and one to two new shoots developed.	Bottom leaves died; adjacent leaves turned yellow with dried out tips; new shoots developed; and adventitious roots formed previously shrank and died.	More leaves died while new leaves developed; some new shoots shrank and died; and adventitious roots formed previously shrank and died.
Mombasa guinea	Stems and leaves green; bottom leaves turned yellow and some died; and new shoots developed.	Stems and leaves green; bottom leaves died while adjacent leaves turned yellow; and new shoots and adventitious roots developed.	More nodes and internodes apparent; more leaves died; new leaves developed; and new shoots and adventitious roots developed.	More leaves died; some leaves yellow; new shoots developed; and adventitious roots formed previously shrank and died.
Purple guinea	Stems, leaf bases, and leaf rims purple while leaf blades green; some bottom leaves died; and one to three new shoots developed.	Stems and leaf bases purple; bottom leaves died while some turned yellow; and new shoots and adventitious roots developed.	Stems purple; many nodes and internodes formed; more leaves died; new shoots developed; and old tillers developed new leaves.	Bottom leaves died but new leaves developed; new shoots developed; and adventitious roots formed previously shrank and died.
Mulato II	Stems and leaves dark green; bottom leaves turned yellow and dried out; and two to five new shoots developed.	Many leaves died and turned yellow with dried out tips; and two to three new shoots and adventitious roots developed.	Nodes and internodes apparent; leaves died, some with dead tips; new shoots developed but some rotted; and adventitious roots developed.	Some plants rotted; many leaves died, some turned yellow, rims died; and new leaves, new shoots, and adventitious roots developed.

Table 4 Morphological changes of six forage grasses at different durations of repeated waterlogging during late vegetative phase (cont.)

Grass	Duration of waterlogging			
	0 day	10 days	20 days	30 days
Cayman	Stems and leaves green; bottom leaves turned yellow and died; and new leaves and new shoots developed.	Stems and leaves green; bottom leaves died, adjacent leaves turned yellow with dried out tips; and new leaves, new shoots, and adventitious roots developed.	Slender stems turned purple; more dried out leaves, some turned yellow and dried out rims; and new leaves, new shoots and adventitious roots developed.	Slender stems with distinct nodes and internodes; many leaves died; and many new shoots developed with small stems.
Humidicola	Slender stems and leaves; bottom leaves dried out; some leaves turned yellow; and many shoots developed.	Slender and small purple stems with distinct nodes and internodes; leaves died and some turned yellow; and new shoots and adventitious roots developed.	Slender small purple stems with distinct nodes and internodes; many leaves died; and some nodes had new shoots and adventitious roots.	Stems had distinct purple nodes and internodes; many leaves died, new shoots developed from both old tillers and nodes; and adventitious roots developed.

Again Ubon paspalum and humidicola performed relatively well under repeated waterlogging; they still developed some new yet smaller leaves and shoots due to the limited reserves available from the main stem (Sampet, 1992). After recovery from the first waterlogging, Mombasa guinea, Mulato II, and Cayman still had more yellow and senesced leaves compared to other grasses indicating a more severe effect of waterlogging and these grasses needed a longer time for recovery and regrowth. In the case of Mulato II, a good cultivar for drought areas (Hare et al., 2009), it was found not to stand repeated excessive water; this grass became rotten after 20 days waterlogging.

2.2 Growth Growth of grasses following repeated waterlogging in terms of plant height, number of tillers, and leaf area were also affected (data not shown). Height, in general, at 30 days recovery of repeated waterlogged grasses were higher than those of control grasses ($P < 0.05$). At 10 days repeated waterlogging, plant height of control and waterlogged grass for the first and second times of waterlogging were 99.0 ± 1.6 vs. 107.2 ± 1.6 and 116.7 ± 2.7 vs. 118.1 ± 2.7 cm respectively. The results suggested that waterlogging stimulated stem elongation for survival from high water level the same as in floating rice that produces more gibberellin and auxin to stimulate internode elongation (Nishiuchi et al., 2012). Humidicola had the longest stem (or plant height) followed by Mombasa guinea, Purple guinea, Ubon paspalum, Cayman, and Mulato II (214.4 ± 4.7, 122.2 ± 4.7, 106.0 ± 4.7, 95.5 ± 4.7, 85.0 ± 4.7, and 81.4 ± 4.7 cm respectively after recovery of 10 days waterlogging).

Repeated waterlogging reduced the number of tillers/hill and leaf area of grasses in all treatments ($P < 0.05$). In the first and second times of waterlogging of 10 days period waterlogged grasses produced only 15.3 ± 0.6 and 17.8 ± 1.0 tillers/hill compared to 18.0 ± 0.6 and 24.9 ± 1.0 tillers/hill respectively in control grasses; and 3,232 ± 373 and 3,500 ± 273 cm^2/hill of leaf area compared to 5,391 ± 373 and 7,918 ± 273 cm^2/hill respectively in control grasses. This was probably due to the insufficient nitrogen and phosphorus supply and the accumulation of toxic substance (Whiteman, 1980) from the poor root system, both elements have major role in tillering of grasses (Tudsri, 2004). Humidicola, Mulato II, and Cayman produced similar number of tillers/hill and roughly twice those of the other grasses; whereas Ubon paspalum, Mombasa guinea, and Purple guinea still produced relatively more leaf area than other grasses.

2.3 Dry weight Waterlogging once and followed by a 30 days recovery period seemed to do no harm on grasses in terms of total dry weight; but repeated waterlogging (with 30 days recovery as well) reduced total dry weight of those under waterlogged conditions ($P < 0.05$; **Table 5**). This showed that a period of time was needed for grasses to recover from excessive water, however this could not help in case of repeated waterlogging. Grasses under repeated waterlogging produced higher senesced leaf dry weight ($P < 0.05$), lower green leaf dry weight (≈ 2 times lower), and lower stem dry weight (data not shown). However one time waterlogging seemed not to reduce stem dry weight, consequently this did not clearly reduce total dry weight as mentioned above.

Table 5 Effect of repeated waterlogging with 30 days recovery period at late vegetative phase on total dry weight of six forage grasses

Factor	Treatment	Total dry weight (g)					
		W10R30[1/]		W20R30		W30R30	
		1	2	1	2	1	2
Waterlogging	Control	35.0 ± 2.0[b2/]	93.8 ± 3.7[a]	50.4 ± 3.0	97.1 ± 4.7[a]	57.5 ± 3.6	126.1 ± 5.7[a]
(A)	Waterlogged	47.8 ± 2.0[a]	70.7 ± 3.7[b]	51.8 ± 3.0	77.6 ± 4.7[b]	60.3 ± 3.6	91.0 ± 5.7[b]
	Average	**41.4**	**82.3**	**51.1**	**87.4**	**58.9**	**108.6**
Grass	UP[3/]	50.4 ± 3.4[a]	91.6 ± 6.4	58.4 ± 5.2	95.7 ± 8.1[ab]	68.0 ± 6.2	118.0 ± 9.9
(B)	MG	42.0 ± 3.4[ab]	82.5 ± 6.4	54.1 ± 5.2	79.1 ± 8.1[b]	53.1 ± 6.2	98.4 ± 9.9
	PG	36.3 ± 3.4[b]	82.1 ± 6.4	52.0 ± 5.2	76.4 ± 8.1[b]	52.4 ± 6.2	83.0 ± 9.9
	MU	35.0 ± 3.4[b]	80.1 ± 6.4	45.1 ± 5.2	73.4 ± 8.1[b]	47.0 ± 6.2	97.2 ± 9.9
	CM	43.8 ± 3.4[ab]	77.9 ± 6.4	55.1 ± 5.2	86.3 ± 8.1[b]	63.1 ± 6.2	119.4 ± 9.9
	BH	40.9 ± 3.4[ab]	79.1 ± 6.4	41.8 ± 5.2	113.0 ± 8.1[a]	69.7 ± 6.2	135.4 ± 9.9
	Average	**41.4**	**82.3**	**51.1**	**87.4**	**58.9**	**108.6**
CV (%)		23.3	22	28.7	26.2	29.9	25.7
LSD	A	5.7	10.6	ns[4/]	13.4	ns	16.3
($P < 0.05$)	B	9.8	ns	ns	23.2	ns	ns
	A x B	13.9	9.3	ns	32.8	25.3	39.9

[1/] W… = days of waterlogging and R… = days of recovery (twice)

[2/] Within a column for each effect, values followed by different letters are significantly different ($P < 0.05$)

[3/] UP = Ubon paspalum, MG = Mombasa guinea, PG = Purple guinea, MII = Mulato II, Cm = Cayman, and BH = *Brachiaria humidicola*

[4/] ns = non significant

In general, Ubon paspalum and humidicola performed well, while Mulato II performed poorly in terms of total dry weight under repeated waterlogging.

2.4 Waterlogging tolerance Humidicola tolerated best to repeated waterlogging (top scores of 39, 41, and 39 for 10, 20, and 30 day periods) followed by Ubon paspalum (30, 32, and 33) and Cayman (22, 25, and 28); other grasses especially Mulato II, did not recover well after repeated waterlogging (**Table 6**).

Table 6 Scores and ranks for repeated waterlogging tolerance of six forage grasses

Parameter	W10R30[1/]						W20R30						W30R30					
	UP[2/]	MG	PG	MII	Cm	BH	UP	MG	PG	MII	Cm	BH	UP	MG	PG	MII	Cm	BH
Plant ht	3	1	3	5	4	6	4	2	2	3	4	6	5	2	3	2	4	6
No. of tillers	4	2	5	3	2	6	6	3	3	1	3	6	6	2	4	2	4	4
Leaf area	5	4	4	2	2	5	5	3	3	3	3	5	5	3	2	1	5	6
Senesced leaf dwt.[3/]	3	4	2	3	6	4	2	4	2	5	3	6	2	2	6	4	5	5
Green leaf dwt.	5	3	4	2	2	6	5	2	3	3	4	6	5	2	3	2	4	6
Stem dwt.	5	3	4	2	3	6	5	3	3	2	4	6	5	3	3	2	3	6
Total dwt.	5	3	4	2	3	6	5	2	3	2	4	6	5	3	3	2	3	6
Total score	30	20	26	19	22	39	32	19	19	19	25	41	33	17	24	15	28	39
Rank	2	5	3	6	4	1	2	4	4	4	3	1	2	5	4	6	3	1

[1/] W… = days of waterlogging and R… = days of recovery (twice)

[2/] UP = Ubon paspalum, MG = Mombasa guinea, PG = Purple guinea, MII = Mulato II, Cm = Cayman, and BH = *Brachiaria humidicola*

[3/] dry weight

Humidicola recovered very quickly during the 30 days recovery period by producing the highest total dry weight, enforcing the findings of Cardoso et al. (2013) that this grass tolerates well to waterlogging. Since it is a procumbent stoloniferous grass this might be the reason of relatively high but not consistent leaf area and more senesced leaves (see 1.4). Whereas Ubon paspalum had a good tillering capacity even under repeated waterlogging. This helped push this grass to number 2 in ranking.

Conclusions

1. Waterlogged grasses had yellow and dried out bottom leaves and more adventitious roots; growth in terms of height, number of tillers, and leaf area were lower; and total dry weight started to become lower at 40 days of waterlogging compared to those of control. Among these six grasses, Ubon paspalum tolerated best to waterlogging followed by humidicola, Cayman, Purple guinea, Mombasa guinea, while Mulato II was the most susceptible.

2. Repeated waterlogging with a recovery period caused yellowish and dried out of bottom leaves, stimulated the production of adventitious roots, new leaves, and new shoots. Grass growth in terms of plant height was higher, but the number of tillers and leaf area were lower compared to those of control. Waterlogging once with a recovery period seemed to do no harm on grasses; but repeated waterlogging with a recovery period as well reduced total dry weight. Among these six grasses, humidicola tolerated best to repeated waterlogging, followed by Ubon

paspalum, Cayman, Purple guinea, Mombasa guinea, while Mulato II was the most susceptible.

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